AUTOMATING THE PROCESS FOR LOCATING NO-PASSING ZONES USING GEOREFERENCING DATA

A Ph.D. Dissertation Proposal
By
MEHDI AZIMI

Submitted to the Office of Graduate Studies
Texas A&M University
in partial fulfillment of the requirement for the degree of
DOCTOR OF PHILOSOPHY

Committee Members:
Dr. Gene Hawkins (Chair)
Dr. Russell Feagin
Dr. Dominique Lord
Dr. Yunlong Zhang

July 1, 2011

Major Subject: Civil Engineering
# TABLE OF CONTENTS

1. INTRODUCTION ................................................................................................................... 1  
2. PROBLEM STATEMENT ......................................................................................................... 1  
3. RESEARCH OBJECTIVES ...................................................................................................... 1  
4. BACKGROUND .................................................................................................................. 2  
  4.1. Passing Sight Distance ........................................................................................................ 3  
    4.1.1. ASHTO Green Book ..................................................................................................... 3  
    4.1.2. Manual on Uniform Traffic Control Devices .............................................................. 6  
  4.2. No-Passing Zones ............................................................................................................ 10  
  4.3. No-Passing Zone Location Methods .................................................................................. 11  
  4.4. Global Positioning System (GPS) ...................................................................................... 11  
    4.4.1 WAAS .......................................................................................................................... 12  
    4.4.2. DGPS ........................................................................................................................... 13  
    4.4.3. RTK ............................................................................................................................. 13  
  4.5. GPS Data, Format and Accuracy ....................................................................................... 14  
  4.6. Geometric Roadway Modeling .......................................................................................... 17  
5. RESEARCH TASKS ............................................................................................................. 18  
  5.1. Literature Review ............................................................................................................... 19  
  5.2. GPS Data Collection and Formatting GPS Data ............................................................... 19  
  5.3. Geometric Modeling of Highway ...................................................................................... 21  
  5.4. No-Passing Zone Algorithm Development ........................................................................ 22  
  5.5. Software Package Development ......................................................................................... 24  
  5.6. Error Estimation of the Developed Model ......................................................................... 24  
  5.7. Prototype Model Development and Evaluation ................................................................. 25  
  5.8. Implementation Guidelines ............................................................................................... 26  
6. POTENTIAL BENEFIT OF STUDY ................................................................................... 26  
7. SCHEDULE OF ACTIVITIES ............................................................................................. 27  
REFERENCES ............................................................................................................................. 28
1. **INTRODUCTION**
Two-lane, two-way highways constitute the vast majority of the road system in the U.S. Over 62 percent of the 80,000 centerline highway miles on the TxDOT system are rural two-lane highways (1). No-passing zones are a significant characteristic of two-lane highways as they establish locations where passing is prohibited because of restricted sight distance. Locating the start and end of these zones can be a major challenge. Many methods for locating no-passing zones are available but there is a need for new methods that can locate no-passing zones in an efficient, accurate, and safer manner. This research will use GPS data and apply theoretical approaches to evaluate horizontal and vertical alignment sight distances in order to develop a method for automating the process for locating no-passing zones.

2. **PROBLEM STATEMENT**
Locating highway segments that require no-passing zones has been a difficult task because of the amount of the time necessary to locate the zones and the hazard involved in working on the highway in the presence of moving traffic. Multiple methods for measuring passing sight distance and determining no-passing zone are available and range in cost, time, and accuracy. Although there are several methods for identifying no-passing zones, each one has a set back because of the time required, accuracy obtained, and related safety issues. Hence, new methods that will efficiently locate no-passing zones, define the no-passing zones accurately, and do so safely are needed. GPS has the potential to meet these needs; however, processes for gathering roadway GPS data, smoothing GPS data, mathematically locating no-passing zones from GPS data, and implementing the results in the field must be addressed. It is believed that a system (prototype) enabling work crews to drive on two-lane roadways with GPS units to automatically determine no-passing zones can be developed by focusing on these issues.

3. **RESEARCH OBJECTIVES**
The goal of the research is to develop a safe, reliable, fast, and accurate system which automates the process for locating no-passing zones; and would be applicable to roadways with changes in both horizontal and vertical alignment. To this end, the research entails the following objectives:
• identify the processes necessary to smooth GPS data and geometrically model roadway surface
• create an algorithm for locating no-passing zones from modeled roadway surfaces due to horizontal and vertical sight obstructions
• develop software package and prototype model that can be used by engineers in the field to establish the location of no-passing zones
• provide guidelines for field implementation of the system

4. BACKGROUND
The criteria for locating no-passing zones are contained in the Manual on Uniform Traffic Control Devices (MUTCD). Location of a no-passing zone for a new highway can be determined from a set of plans, but the location needs to be confirmed in the field due to potential differences between the plans and the actual construction. Locating no-passing zones in the field typically involves surveying activities or two vehicles connected by a rope associated with the appropriate passing sight distance. Both methods are time consuming, expensive, subject to error, and can significantly impact other vehicles traveling on the roadway. Furthermore, these procedures place workers in the presence of moving traffic. In addition to determining the location of no-passing zones for a new highway, the location need to be reestablished whenever the speed limit changes, when obstacles are placed that block the sight distance in the vertical or horizontal plane, and sometimes when the pavement is resurfaced. Therefore, there is a need for an automated method to locate no-passing zones that is ready for implementation by transportation agencies. Previous research efforts have addressed some aspects related to this need (2, 3), but none of them have produced a comprehensive product that is ready for implementation. This research intends to develop a method for locating no-passing zones that is based on GPS and would consider both horizontal and vertical alignment perspectives of the roadway. The development of such an automated system could save time and cost, avoid human errors, and be safer compared to the current methods of the field measurements.
4.1. Passing Sight Distance

Sight distance is the length of roadway visible to a driver. The American Association of State Highway and Transportation Officials (AASHTO) states that the designer should provide sufficient sight distance for the drivers to control operation of their vehicles before striking unexpected objects in the traveled way (4). Two-lane highways should also have sufficient sight distance to provide opportunities for faster drivers to occupy the opposing traffic lane for passing other vehicles without risk of a crash where gaps in opposing traffic permit. Two-lane rural highways should generally provide such passing sight distance at frequent intervals and for substantial portions of their length.

Two types of passing sight distance criteria for two-lane highways are used by highway agencies: geometric design and marking criteria. Therefore, separate criteria are used in designing the highways and in marking no-passing zones on the highways. The AASHTO Green Book and MUTCD both cover the subject of passing sight distance. The contents of these documents are briefly covered below.

4.1.1. AASHTO Green Book

AASHTO Green Book (4) presents a model for determining the passing sight distance based on the results of field studies conducted between 1938 and 1958 (5). The model incorporates three vehicles, and is based on five assumptions:

1. The vehicle being passed travels at a constant speed.
2. The passing vehicle follows the slow vehicle into the passing section.
3. Upon entering the passing section, the passing driver requires a short period of time to perceive that the opposing lane is clear and to begin accelerating.
4. The passing vehicle travels at an average speed that is 10 mph faster than the vehicle being passed while occupying the left lane.
5. When the passing vehicle returns to its lane, there is an adequate clearance distance between the vehicle and an oncoming vehicle in the other lane.

AASHTO passing sight distance is the sum of four distances, as following (Figure 1 gives a graphical explanation of these elements):

\[ S = d_1 + d_2 + d_3 + d_4 \]
where:

\[ S = \text{minimum passing sight distance} \]

\[ d_1 = \text{distance traversed during perception and reaction time and during initial acceleration to } \]
\[ \text{the point of encroachment on the left lane;} \]

\[ d_2 = \text{distance traveled while the passing vehicles occupies the left lane.} \]

\[ d_3 = \text{distance between the passing vehicle at the end of its maneuver and the opposing } \]
\[ \text{vehicle.} \]

\[ d_4 = \text{distance traversed by an opposing vehicle for two-thirds of the time the passing vehicle } \]
\[ \text{occupies the left lane, or } 2/3 \text{ of } d_2 \text{ above.} \]

![Figure 1. Elements of Passing Sight Distance for Two-Lane Highways](Exhibit 3-4, AASHTO Green Book)

Table 1 summarizes the results of field observations directed toward quantifying the various aspects of the passing sight distance.
Table 1. Elements of Safe Passing Sight Distance for Design of Two-Lane Highways
(Exhibit 3-5, AASHTO Green Book)

<table>
<thead>
<tr>
<th>Component of Passing Maneuver</th>
<th>Speed Range (mph)</th>
<th>Average Passing Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30-40</td>
<td>40-50</td>
</tr>
<tr>
<td>Initial Maneuver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a=average acceleration (mph/sec)</td>
<td>1.40</td>
<td>1.43</td>
</tr>
<tr>
<td>t1=time (sec)</td>
<td>3.6</td>
<td>4.0</td>
</tr>
<tr>
<td>d1=distance traveled (ft)</td>
<td>145</td>
<td>216</td>
</tr>
<tr>
<td>Occupation of Left Lane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t2=time (sec)</td>
<td>9.3</td>
<td>10.0</td>
</tr>
<tr>
<td>d2=distance traveled (ft)</td>
<td>477</td>
<td>643</td>
</tr>
<tr>
<td>Clearance Length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d3=distance traveled (ft)</td>
<td>100</td>
<td>180</td>
</tr>
<tr>
<td>Opposing Vehicle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d4=distance traveled (ft)</td>
<td>318</td>
<td>429</td>
</tr>
<tr>
<td>Total Distance, d1+d2+d3+d4</td>
<td>1040</td>
<td>1468</td>
</tr>
</tbody>
</table>

The design lengths for passing sight distances for various speeds and the corresponding individual values of d₁, d₂, d₃, and d₄ are shown in Figure 2.

Figure 2. Total Passing Sight Distance and Its Components – Two-Lane Highways
(Exhibit 3-6, AASHTO Green Book)
AASHTO recommends minimum passing sight distances between 710 and 2680 feet for two-lane highways for design speeds ranging from 20 to 80 mph (see Table 2). These values are based on the driver’s eye height being 3.5 feet and the height of the object being 3.5 feet.

### Table 2: Passing Sight Distance for Design of Two-Lane Highways

(Exhibit 3-7, AASHTO Green Book)

<table>
<thead>
<tr>
<th>Design Speed (mph)</th>
<th>Assumed Speeds (mph) Passed Vehicle</th>
<th>Passing Vehicle</th>
<th>Passing Sight Distance (ft) Calculated</th>
<th>Rounded for Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>18</td>
<td>28</td>
<td>706</td>
<td>710</td>
</tr>
<tr>
<td>25</td>
<td>22</td>
<td>32</td>
<td>897</td>
<td>900</td>
</tr>
<tr>
<td>30</td>
<td>26</td>
<td>36</td>
<td>1088</td>
<td>1090</td>
</tr>
<tr>
<td>35</td>
<td>30</td>
<td>40</td>
<td>1279</td>
<td>1280</td>
</tr>
<tr>
<td>40</td>
<td>34</td>
<td>44</td>
<td>1470</td>
<td>1470</td>
</tr>
<tr>
<td>45</td>
<td>37</td>
<td>47</td>
<td>1625</td>
<td>1625</td>
</tr>
<tr>
<td>50</td>
<td>41</td>
<td>51</td>
<td>132</td>
<td>1835</td>
</tr>
<tr>
<td>55</td>
<td>44</td>
<td>54</td>
<td>1984</td>
<td>1985</td>
</tr>
<tr>
<td>60</td>
<td>47</td>
<td>57</td>
<td>2133</td>
<td>2135</td>
</tr>
<tr>
<td>65</td>
<td>50</td>
<td>60</td>
<td>2281</td>
<td>2285</td>
</tr>
<tr>
<td>70</td>
<td>54</td>
<td>64</td>
<td>2479</td>
<td>2480</td>
</tr>
<tr>
<td>75</td>
<td>56</td>
<td>66</td>
<td>2578</td>
<td>2580</td>
</tr>
<tr>
<td>80</td>
<td>58</td>
<td>68</td>
<td>2677</td>
<td>2680</td>
</tr>
</tbody>
</table>

### 4.1.2. Manual on Uniform Traffic Control Devices

The AASHTO passing sight distance values presented in Table 2 are used for design purposes only. The Manual on Uniform Traffic Control Devices (MUTCD) developed by the Federal Highway Administration (6), lays out minimum passing sight distance for placing no-passing zone pavement markings on completed highways. The MUTCD criteria were first incorporated in the 1948 MUTCD, identical to those presented in the 1940 AASHO policy on marking no-passing zones (7), and were used as warrants for no-passing zones (5). The warrants are based on a compromise between delayed and flying passes. A delayed pass is a maneuver in which the passing vehicle slows down before making pass. A flying pass is a maneuver in which the passing vehicle is not delayed by the slower, passed vehicle. Table 3 presents the sight distances for flying and delayed passes and the minimum sight distances suggested by the 1940 AASHO policy on marking no-passing zones (7).
Table 3: Sight Distances for Flying and Delayed Passes (7)

<table>
<thead>
<tr>
<th>V, assumed design speed of the road (mph)</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td>m, difference in speed between the assumed design speed of the road and the assumed speed of the overtaken vehicle (mph)</td>
<td>10</td>
<td>12.5</td>
<td>15</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>V₀, assumed speed of an opposing vehicle comes into view just when the passing maneuver is begun (mph)</td>
<td>25</td>
<td>32.5</td>
<td>40</td>
<td>47.5</td>
<td>55</td>
</tr>
<tr>
<td>Sight Distances for Flying Passes (ft)</td>
<td>440</td>
<td>550</td>
<td>660</td>
<td>660</td>
<td>660</td>
</tr>
<tr>
<td>Sight Distances for Delayed Passes (ft)</td>
<td>510</td>
<td>760</td>
<td>1090</td>
<td>1380</td>
<td>1780</td>
</tr>
<tr>
<td>Suggested Minimum Sight Distances (ft)</td>
<td>500</td>
<td>600</td>
<td>800</td>
<td>1000</td>
<td>1200</td>
</tr>
</tbody>
</table>

In the table, V denotes the *assumed design speed* of the road and is defined as following (7):

“The assumed design speed is considered to be the maximum approximately uniform speed which probably will be adopted by the faster group of drivers but not, necessarily, by a small percentage of reckless ones.”

“The design speed of an existing road or section of road may be found by measuring the speed of travel when the road is not congested, plotting a curve relating speeds to numbers or percentages of vehicles and choosing a speed from the curve which is greater than the speed used by almost all drivers. It may also be found by driving the road until a comfortable maximum uniform speed is found.”

Table 4 lists the MUTCD recommended minimum passing sight distances for various speeds. Although MUTCD adopted the same minimum passing sight distances from the 1940 AASHO policy on marking no-passing zones, it defines the symbol V as 85th-percentile/posted/statutory speed rather than design speed (see Table 4).
Table 4: Minimum Passing Sight Distances for No-Passing Zones Markings  
(\textit{Table 3B-1, MUTCD})

<table>
<thead>
<tr>
<th>85\textsuperscript{th} Percentile or Posted or Statutory Speed Limit (mph)</th>
<th>Minimum Passing Sight Distance (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>450</td>
</tr>
<tr>
<td>30</td>
<td>500</td>
</tr>
<tr>
<td>35</td>
<td>550</td>
</tr>
<tr>
<td>40</td>
<td>600</td>
</tr>
<tr>
<td>45</td>
<td>700</td>
</tr>
<tr>
<td>50</td>
<td>800</td>
</tr>
<tr>
<td>55</td>
<td>900</td>
</tr>
<tr>
<td>60</td>
<td>1000</td>
</tr>
<tr>
<td>65</td>
<td>1100</td>
</tr>
<tr>
<td>70</td>
<td>1200</td>
</tr>
</tbody>
</table>

The MUTCD passing sight distance criteria are measured based on 3.5 ft height of driver eye and 3.5 ft height of object (the 3.5 ft height of object allows the driver to see the top of a typical passenger car). In other words, it is assumed that the driver's eyes are at a height of 3.5 ft from the road surface and the opposing vehicle is 3.5 ft tall. The actual passing sight distance is the length of roadway ahead over which the object would be visible. On a vertical curve, it is the distance at which an object 3.5 feet above the pavement surface can be seen from a point 3.5 feet above the pavement (see Figure 3). Similarly, on a horizontal curve, it is the distance measured along the center line between two points 3.5 feet above the pavement on a line tangent to the embankment or other obstruction that cuts off the view on the inside of the curve (see Figure 4).
Figure 3: Passing Sight Distance at Vertical Curve (Figure 3B-4, MUTCD)

Figure 4: Passing Sight Distance at Horizontal Curve (Figure 3B-4, MUTCD)
As it was explained, the minimum passing sight distances suggested by AASHTO Green Book and the MUTCD are based on different assumptions. The AASHTO criteria are not used in the marking of no-passing zones. The MUTCD presents considerably shorter passing sight distance values, derived for traffic-operating control needs and for marking standards. Figure 5 compares the passing sight distance values resulting from the AASHTO Green Book and MUTCD.

![Figure 5. Comparison of Passing Sight Distance Values for AASHTO Green Book and MUTCD](image)

**4.2. No-Passing Zones**

No-passing zones, represented by solid lines marked in the centerline of two-lane highways, forewarn drivers of the segments of highway that contain sight restrictions and therefore should not be used to make passing maneuvers. The 2009 MUTCD states the following in reference to no-passing zone marking (6):

“On two-way, two- or three-lane roadways where center line markings are installed, no-passing zones shall be established at vertical and horizontal curves and other locations...
where an engineering study indicates that passing must be prohibited because of inadequate sight distances or other special conditions.”

“On roadways with center line markings, no-passing zone markings shall be used at horizontal or vertical curves where the passing sight distance is less than the minimum shown in Table 4 for the 85th-percentile speed or the posted or statutory speed limit.”

Neither the AASHTO Green Book nor MUTCD addresses required minimum lengths for passing zones. But the MUTCD indirectly sets a minimum passing zone length of 400 ft by providing guidance which was first included in the 1961 edition (5) and is still included in the current version of the manual (6):

“Where the distance between successive no-passing zones is less than 400 ft, no-passing zone markings should connect the zones.”

4.3. No-Passing Zone Field Location Methods

There are multiple methods for measuring passing sight distance and determining no-passing zone in the field including Walking (Two-Person) Method, One-Vehicle Method, Two-Vehicle Method, Eyeball Method, New Jersey Cone Method, Towed-Target Method, Laser Rangefinder Method, Optical Rangefinder Method, Distance Measuring Equipment Method, Remote-Control Vehicle, Speed and Distance Method, and Videolog/Photolog Method (8, 9, 10).

Although there are several methods for identifying no-passing zones, each one has a set back because of the time required, accuracy obtained, and related safety issues. Additionally, they rely on judgment in determining the beginning and ending of no-passing zones. However, it is assumed that by using Global Positioning System (GPS) the location of the no-passing zones could be obtained more quickly, accurately, and safely.

4.4. Global Positioning System (GPS)

Global Positioning System (GPS) is a satellite-based radio-navigation system that provides reliable location information where there is an unobstructed line of sight to four or more GPS satellites. The system provides spatial coordinate triplets of longitude, latitude, and elevation for each point. GPS is maintained by the United States government and consists of three parts: the space segment, the control segment, and the user segment. The space segment is composed of
24 to 32 satellites and also includes the boosters required to launch them into orbit. The control segment is composed of a master and alternate control, and a host of ground antennas and monitor stations. The user segment is composed of users of the Standard Positioning Service. There are factors that can degrade the GPS signal and thus affect the accuracy of GPS. The factors include *ionosphere and troposphere delays, signal multipath, receiver clock errors, orbital errors, number of satellites visible*, and *satellite geometry/shading*. High-end GPS systems reduce GPS errors and provide more accurate and reliable readings by using a differential signal broadcasted from either known locations (reference stations) on Earth or other satellite networks. Reference stations track the satellites and have a true range to each satellite (the exact number of wave-lengths between itself and the satellite). This information, along with its known location, is sent to the receiver (see Figure 6). High-end GPS devices are usually divided into four categories with different accuracy levels: WAAS, DGPS (sub-meter and decimeter), and RTK (centimeter) systems. It should be noted that many vendors are highly optimistic on claimed accuracy, and most of those accuracies are based on pass-to-pass accuracy and not repeatability (12). Repeatability is the ability to return to the exact same location at any time.

![Figure 6. GPS Signal Correction](image)

4.4.1 WAAS

WAAS stands for *Wide Area Augmentation System*. A WAAS-capable receiver can provide a position accuracy of better than ten feet 95 percent of the time. WAAS consists of approximately 25 ground reference stations positioned across the United States that monitor GPS
satellite data. Two master stations, located on either coast, collect data from the reference stations and create a GPS correction message. The corrected differential message is then broadcast through one of two geostationary satellites, or satellites with a fixed position over the equator. The information is compatible with the basic GPS signal structure, which means any WAAS-enabled GPS receiver can read the signal. For some users in the U.S., the position of the satellites over the equator makes it difficult to receive the signals when trees or mountains obstruct the view of the horizon. WAAS signal reception is ideal for open land and marine applications. WAAS provides extended coverage both inland and offshore compared to the land-based DGPS system (11).

4.4.2. DGPS
Differential Global Positioning System (DGPS) is an extension of the GPS system that uses land-based radio beacons to transmit position corrections to GPS receivers. It consists of a network of towers that receive GPS signals and transmit a corrected signal by beacon transmitters. In order to get the corrected signal, users must have a differential beacon receiver and beacon antenna in addition to their GPS. DGPS systems require a differential signal from either a free service or a commercial service. One of the famous free services is Coast Guard Beacon. OmniStar and John Deere’s StarFire (SF) systems are in the list of commercial services. Those services need subscription and the cost of their subscription varies. OmniStar VBS costs $800 per year and requires only a single channel receiver. OmniStar HP costs $1500 per year and requires a dual channel receiver. The SF I is a free signal for those who buy the hardware, and the SF II costs $800/yr. SF II requires a dual channel receiver like OmniStar HP (12).

4.4.3. RTK
Real Time Kinematic (RTK) is not only the most accurate of all GPS systems, but the only system that can achieve complete repeatability, allowing a user to return to the exact location, indefinitely. RTK utilizes two receivers: a static ground base station and one or more roving receivers. The base station receives measurements from satellites and communicates with the roving receiver(s) through a radio link. The roving receiver processes data in real-time to produce an accurate position relative to the base station. All of this produces measurements with an immediate accuracy to within 1 to 2 inches. The total cost of a full RTK system with base
station, receiver, data logger, and software is usually around $40,000 (12). In addition to the high cost of the system, there are some issues related to applying the RTK systems. For example, there always needs to be line of sight between the ground station of the RTK and the roving receiver; and the distance between them should always be within 6 to 10 miles. The receiver must also simultaneously track five satellites to become initialized, and then continue to track four satellites to remain initialized. Furthermore, RTK needs a time up to 30 minutes before it begins initialization (12).

### Table 5. Comparison of Different GPS Devices

<table>
<thead>
<tr>
<th>Basic GPS Devices</th>
<th>High-End GPS Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Price Range</strong></td>
<td>WAAS</td>
</tr>
<tr>
<td>$&lt; 100$</td>
<td>$100 - 500$</td>
</tr>
<tr>
<td><strong>Source of Signal Correction</strong></td>
<td>-</td>
</tr>
<tr>
<td><strong>Accuracy</strong>¹</td>
<td>10 - 100 feet</td>
</tr>
<tr>
<td><strong>Advantage</strong></td>
<td>lowest cost, small handheld unit, no additional equipment or service fees are required</td>
</tr>
</tbody>
</table>

1. Accuracy in horizontal position
2. Repeatability is the ability to return to the exact same location at any time.

### 4.5. GPS Data, Format and Accuracy

The true figure of the Earth is spheroid or ellipsoid. Every position on Earth is uniquely defined by GPS data in the format of longitude \( \lambda \), latitude \( \varphi \), and altitude above or below sea level. Longitude and latitude are angles measured from the earth’s center to a point on the earth’s surface (Figure 7). The angles are measured in degrees or in grads.
Young and Miller (14) showed that the spatial error from successive GPS data is highly correlated. Even though the GPS error is widely published to be in the range of 1 to 5 meters, the relative accuracy of sequential GPS data is much greater. If successive GPS data points use the same constellation of satellites, the relative error between the two data points is minimal. Assuming absolute errors of 2 m and 5 m, respectively, for horizontal and vertical error, the relative error between successive readings is easily sub-meter in both dimensions. The error correlation between successive GPS data was estimated between the 0.99- and 0.999-level in the work performed by Young and Miller (14). They showed that the absolute position error of their three-dimensional model is reduced as a function of the number of observations. Figure 8 shows the hypothetical reduction in the absolute position error of the 3D model as a function of the number of observations, assuming 2-m and 5-m random errors, respectively, for horizontal and vertical positions.
Young and Miller believed that the high correlation of GPS data error provides in essence a high quality estimate of heading in the horizontal plane and grade in the vertical plane. Additional error reduction arises because successive estimates of slope are highly independent, unlike position estimates. Figure 9 indicates that the relative shape of the roadway is consistently captured in the GPS data, despite the differences in absolute elevation. Since the researcher did not collect the GPS data in the field but used GPS data from previous roadway inventory, the figures suggest that possibly several different GPS receivers, each with a different bias, were used to collect the elevation data.
4.6. Geometric Roadway Modeling

Kansas Department of Transportation (KDOT) collected spatial data on a highway system using annual GPS surveys. Ben-Arieh et al. (15) described a methodology for cleaning up this large amount of data, considering it, and generating an approximation of the highway. Nehate and Rys (16) developed a model using GPS data for determining the available sight distance on 3D combined horizontal and vertical alignments. Piecewise parametric equations in the form of cubic B-splines were used to represent the highway surface and sight obstructions, including tangents (grades), horizontal curves, and vertical curves. Namala and Rys (17) developed a model for measuring passing sight distance and identifying no-passing zones. Their model was based on AASHTO design guidelines for passing sight distances and MUTCD criteria for marking no-passing zones. However, in practice the MUTCD is the only field guide used for marking no-passing zones. Furthermore, they used GPS data from previous roadway inventory logs obtained from data collection vehicles and didn’t test their model in the field for locating the no-passing zones. Young and Miller (14) addressed many of the errors associated with GPS data and methods for combining historically logged roadway data from KDOT. Easa et al. (18) developed an analytical model for creating vertical profiles from field data. The model divided
roadways into segments of tangents, crest curves, and sag curves based on trends in incremental slopes of field data points. Then the tangents and vertical curve segments were fit by linear regression and splines, respectively. To identify the vertical profiles of roadways from field data, Easa (19) developed an algorithm for determining optimum vertical alignments from field data based on optimization methods. Makanae (20) examined an application of parametric curves used as spatial curves to highway alignment. The study showed that cubic and quadratic B-spline curves are suitable for application to highway alignment with a relatively large and small radius of curvature, respectively.

5. RESEARCH TASKS
This research will develop a method for automating the process for locating no-passing zones by building upon the theoretical approaches used by others for vertical alignment (3) and developing new theoretical concepts to address the horizontal alignment concepts. The research will begin with reviews of traditional methods used to locate no-passing zones and prior research to develop automated methods. The next activity will be to determine the optimal method for collecting and formatting GPS data or use existing GPS data provided by highway agencies. Then the main research activity will be to develop an analytical algorithm to locate no-passing zones that considers both horizontal and vertical alignments. The vertical alignment sight distance is expected to be based on whether the pavement surface blocks the sight line between the observer and target. The horizontal alignment sight distance is expected to be based on a width of roadway (including the traveled way, shoulders, and roadside) defined by the user to be free of sight obstructions. Being able to combine the sight distance information for the vertical and horizontal alignment is another key aspect of this activity. The result of these two main activities will be a preliminary prototype method that is ready for experimental evaluation. Once ready, the preliminary prototype will be used to collect data in the field and identify the recommended locations for no-passing zones. The recommended locations will be compared to the actual locations. In addition, the accuracy of the actual locations will be evaluated for some portion of the sample to ensure that the existing no-passing zone markings are properly located. The results of the evaluation will be used to develop the final prototype and the necessary material so that the prototype can be fabricated by others. The final prototype expected to
consist of a laptop computer, a software package developed through this project, and a GPS receiver. The research tasks are explored below.

5.1. Literature Review
The initial step in this study is a thorough literature review on the subject to understand the previous work and topics associated with the research. This background information will aid the researcher throughout the entire process. Specific areas of interest for the literature review are:

a) brief history of no-passing zones
b) vertical and horizontal alignment sight distances
c) traditional methods used to locate no-passing zones
d) background on GPS technology
e) previous studies which applied the GPS technology in evaluating sight distances
f) geometric modeling of roadways, and
g) automated location of no-passing zones

5.2. GPS Data Collection and Formatting GPS Data
The purpose of this task is preparing a data collection plan, collecting GPS data, and converting the data to a usable format for input into the model. First, the researcher will develop a data collection plan to identify the sample size of the roadway alignments required for the study, locations of the testing sites, time/date of data collection, etc. Sample size depends on number of roadway alignments, length of the alignments, and number of horizontal and vertical curves and other critical points in the alignments. Accuracy of the GPS data is another important parameter in selecting sample size.

The focus of the current research is on collecting GPS data for locating no-passing zones. It is clear that for this research, the accuracy in absolute position of the successive GPS data points is not as important as the accuracy of the relative position. Hence, based on the research conducted by Young and Miller (13), collecting GPS data from one location in several runs do not help in improving the accuracy of the data for this study. For example, if multiple GPS runs of the same roadway are collected within 15 minutes of each other, or even an hour, they should have similar errors and have relative accuracy when compared to one another. However, it is
better to collect more than one sample run from each roadway since it might happen that some points of the data are missing due to the positions of the satellites and obstructions.

GPS receivers with different technologies are available today to be used in the data collection but it is not in the scope of this research to analyze and evaluate each option. Instead two accessible GPS equipments which have different high-end technologies (WAAS and DGPS) will be used for the data collection. The Center for Transportation Safety at the Texas Transportation Institute (TTI) has two types of GPS packages from different manufacturers which have different capabilities: GeoChron Blue and Trimble® DSM232. The reason for using two different GPS equipments is comparing the results of the data in Task 8 (Prototype Model Development and Evaluation) and selecting the most appropriate GPS unit for the prototype model, in terms of price and accuracy. The GeoChron Blue (see Figure 10) has WAAS feature and the collection rate capability of this device is one hertz. It means that the GPS data can be collected and stored at a time interval of one second.

![Figure 10. GeoChron Blue - Field-hardened GPS Logger with Bluetooth®](image)

The Trimble® DSM232 system uses commercial satellite correction services provided by OmniSTAR and provides sub-meter accuracy in real time (see Figure 11). The collection rate capability of the unit is ten hertz and accuracy of the device is as following (21):

- X, Y position (differential/RTK): 0.25m / 0.01m
- Height (differential/RTK): 0.5m / 0.02m
Once the GPS raw data are collected in the format of longitudes, latitudes, and altitudes, a suitable map projection should be selected to transform the terrestrial coordinates on the curved surface of the Earth to a planar Cartesian coordinate system. In other words, the longitudes and latitudes ($\lambda$ and $\varphi$) must be converted into easting and northing coordinates (x and y), where x corresponds to the east-west dimension and y to the north-south. A map projection is a mathematical algorithm to transform locations defined on the curved surface of the Earth into locations defined on the flat surface of a map. The conversion of the curved surface to the planar surface is always accompanied with some types of distortion, due to the spheroidal/ellipsoidal figure of the Earth. However, map projection can preserve one or several characteristics of the surface at the cost of distorting other features. Therefore, selection of the most suitable map projection technique and the equations necessary to accomplish this data conversion will also be performed in this task to apply to the data.

5.3. Geometric Modeling of Highway

Developing the automated method for locating no-passing zones requires having the geometric definition of the roadway alignments. The road obtained using GPS data is represented as a curve rather than a surface. One of the important tasks of this research is smoothing the collected GPS data and obtaining the best curve representing the geometry of two-lane highways.
In this task, the researcher applies a method to smooth the processed GPS data and then, selects a mathematical model to represent the geometric definition for roadway alignments.

The accuracy of GPS data, especially when collected from a moving vehicle, can vary drastically due to the satellite positions; and smooth profiles cannot be taken directly from a single GPS data collection run. However, multiple data collection runs have unnecessary repetitions in data. Therefore a suitable method needs to be selected for cleaning data from repetitions and possible errors. This task has to be performed by using a computer algorithm due to the large amount of data. The algorithm combines the various data streams together, removes outliers, and generates correct spatial points. Then a mathematical curve fitting model for approximation of the highway geometry will be applied. In general, curve fitting models are used for different purposes such as parameter estimation, functional representation, data smoothing, or data reduction. Our objective in this part of the research is to perform a curve fitting process on the set of data points for the purposes of data smoothing and functional representation. Parametric curves defined with piecewise polynomials such as cubic spline curves, Bezier curves, quadratic B-spline curves, and cubic B-spline curves have been used in the previous studies to obtain geometric definition of highways (15, 20). The researcher will examine those models to define the best presentation of highways, along with possible new fitting models (e.g. genetic algorithm). In summary, the mathematical model necessary to smooth the GPS data and to obtain geometric modeling of highway will be selected in this step of the research.

5.4. No-Passing Zone Algorithm Development

After geometric modeling of two-lane highways, the main research activity will be to develop a systematic approach for analyzing smoothed data to locate no-passing zones (no-passing zone algorithm). Previous research efforts have been done related to this need (2, 3); but either they have not been comprehensive products ready for implementation or have addressed only the vertical aspect related to this need. In particular, a recent TAMU master’s thesis addressed using global positioning system (GPS) to automatically locate no-passing zones for vertical alignments, but only the vertical alignment issue was addressed and only from a theoretical perspective.
In two-lane highways, sight distance may be obstructed by horizontal alignments, vertical alignments, or a combination of both. Being able to combine the sight distance information for the vertical and horizontal alignments is the key aspect of this activity. In this task, the researcher will identify the important parameters which must be used in the model to measure horizontal and vertical sight distances. The parameters include height of driver’s eye, height of object, lane width, shoulder width, visual clear zone, etc. Then an analytical algorithm will be developed using projections of the roadway on 2D planes. The input to the algorithm should be the definition of the roadway produced from the smoothing process and geometric modeling task. The output of the algorithm should be starting and ending stations of no-passing zones on a roadway. Considering the MUTCD recommended minimum passing sight distances related to the posted speed of the highway, a no-passing zone for a segment of the roadway will be required where the pavement surface elevation is above the needed sight line in vertical curves. Sight line is defined as a line of sight which is 3.5 feet above the pavement surface on each end. In horizontal curves, no-passing zone is required if the sight line intersects outer edge of visual clear zones in either side of the roadway. Visual clear zones are corridors of unobstructed vision immediately adjacent to the both side of two-lane highways, permitting vehicle drivers to see approaching vehicles. The algorithm will examine the intersection of sight line and roadway surface or other obstructions. An iterative process will be used in the algorithm to measure the horizontal and vertical sight distances. Then the algorithm would compare the resulted sight distances (horizontal and vertical) and select the lower bound to pinpoint location of no-passing zones for that specific segment of the roadway. In this research, we define the lower bound as aggregate overlapping horizontal and vertical sight distances.

According to the MUTCD (6), the passing sight distance on a horizontal curve is the distance measured along the center line between two points (3.5 feet above the pavement) on a line tangent to the embankment or other obstruction that cuts off the view on the inside of the curve (see Figure 4). The data collected with the GPS equipments do not correspond with the roadway centerline since the vehicle that collects the data travels on one direction of the roadway and does not go over the centerline. Assuming the vehicle follows a path centered on its lane and the GPS antenna is mounted on top of the vehicle directly above the center of gravity of the vehicle, the geometric definition of the roadway obtained in Task 3 represents the centerline of the traveled lane. Therefore, the no-passing zone algorithm needs to be developed in such a way
that it determines the location of no-passing zones, not only for the traffic in direction of data collection but for the traffic approaching the opposite direction. No-passing zones for traffic in opposite directions may overlap or there may be a gap between their ends.

5.5. Software Package Development
The purpose of this task is to develop a software package that implements the algorithms designed in the previous steps. This package is a user-friendly software that integrates the programs for GPS conversion, data cleaning, data smoothing, and no-passing zone algorithms. For coding this software, the main objective is to have an efficient program that has an easy-to-use Graphical User Interface (GUI). Therefore several computer programming languages will be examined to find the best one which can code the algorithms easily and also provide a number of features for GUI applications. After coding the algorithms, it will be converted to an executable program file that can run independently on any machine (PC or laptop) without needing to install any special software or program. In this way, the software package can be easily used by both work crews in the field and traffic engineers in the office.

5.6. Error Estimation of the Developed Model
This task deals with the potential sources of error in all steps of developing model and algorithm. The current values for minimum passing sight distances in the MUTCD are based on a compromise between delayed and flying passes (see Figure 12). For example, the sight distances for flying pass and delayed pass (with the design speed of 70 mph) are 550 and 760 feet, respectively. It means that there is a range for the passing sight distance rather than an exact number. However, the suggested minimum sight distances in the manual related to this speed is 600 feet. Therefore, one of the inaccuracies in locating no-passing zones would be due to the origin of the passing sight distance warrants. Furthermore, other potential error in the developed model would be because of inaccuracy in the origin of GPS data, type of GPS receivers, number of data collection runs, and imprecision associated with the smoothing process of the GPS data, geometric modeling of highway, and developing the no-passing zone algorithm. The researcher will examine these potential sources of error and address the way he can account for them.
Prototype Model Development and Evaluation

A preliminary prototype tool instrument will be designed based on the proposed model which could be used in the field to establish the location of no-passing zones on the two-lane highways. The prototype expected to consist of a laptop computer, the software package developed through the project, and a GPS receiver. Other equipments needed to develop the prototype will also be identified. Furthermore, the data collected with two different GPS receivers (GeoChron Blue and Trimble® DSM232) will be compared to study the differences in the results of data collection and no-passing zone location. It will provide the researcher a better idea in selecting the appropriate GPS receiver.

Once ready, the preliminary prototype will be used to collect data in the field and identify the recommended locations for no-passing zones. The recommended locations will be compared to the actual locations. In addition, the accuracy of the actual locations will be verified for some portion of the sample to ensure that the existing no-passing zone markings are properly located. This will be done by travelling to the field and checking the available sight distances. The vehicle can be parked on the shoulder at an adequate distance before the horizontal or vertical curve. Using a laser or optical rangefinder and a distance measuring instrument (DMI), the
distance to a vehicle just disappearing over a hill or around a curve will be measured and compared with the suggested MUTCD minimum passing sight distance. The impact of measurement errors will be studied through sensitivity analyses. The results of the evaluation will be used to develop the final prototype and the necessary material so that the prototype can be fabricated by others.

5.8. Implementation Guidelines
The goal of this research is to develop an efficient and accurate system for automating the process for locating no-passing zones that would consider both horizontal and vertical alignment perspectives of the roadway and also be ready for implementation by transportation agencies. Therefore, it is necessary to establish guidelines and procedures for field implementation by work crews. The guidelines include a simple description of the prototype, steps for setting up the system, steps for data collection to obtain the location of no-passing zones, and description of the results format. Furthermore, some user-defined parameters related to the data collection procedure (including but not limited to the frequency of GPS reading, antenna height of the GPS receiver, and vehicle speed) will be described and documented. After the guidelines are prepared, they will be asked to be reviewed and tested by someone who is unfamiliar with the system in order to check how well he/she can understand and follow the given guidelines. This will help to make further improvements in the guidelines if it feels necessary.

6. POTENTIAL BENEFIT OF STUDY
If this study is successful in developing the model and prototype, it overcomes the disadvantages associated with the current practices and the transportation agencies would be able to more efficiently and accurately locate the potential no-passing zones and thus determine the striping patterns on two-lane highways. Implementing this automated technique and development the prototype has the potential benefits of saving time and cost and eliminating human errors. More importantly, it will not only provide a safer method by which field crews can determine the location of two-lane roadway pavement markings, but also eliminate the need to visually inspect the sight distance of the highway.
7. SCHEDULE OF ACTIVITIES

The following table presents a schedule of activities for the project.

<table>
<thead>
<tr>
<th>Task</th>
<th>Month</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3  4</td>
</tr>
<tr>
<td>1: Literature Review</td>
<td></td>
</tr>
<tr>
<td>2: GPS Data Collection and Formatting GPS Data</td>
<td></td>
</tr>
<tr>
<td>3: Geometric Modeling of Highway</td>
<td></td>
</tr>
<tr>
<td>4. No-Passing Zone Algorithm Development</td>
<td></td>
</tr>
<tr>
<td>5: Software Package Development</td>
<td></td>
</tr>
<tr>
<td>6: Error Estimation of the Developed Model</td>
<td></td>
</tr>
<tr>
<td>7: Prototype Development and Evaluation</td>
<td></td>
</tr>
<tr>
<td>8: Implementation Guidelines</td>
<td></td>
</tr>
</tbody>
</table>
REFERENCES


3. Williams, C. L. Field Location and Marking of No-Passing Zones Due To Vertical Alignments Using the Global Positioning System. MS Thesis, Department of Civil Engineering, Texas A&M University, College Station, Texas, 2008.


